METHOD OF OPTIMIZING PATIENT OUTCOME FROM EXTERNAL COUNTERPULSATION THERAPY

BACKGROUND OF THE INVENTION

Cross Reference to Co-Pending Provisional Application

5   This application claims the benefit of Provisional Application No. 60/453,989, filed March 12, 2003, the entire content of which is hereby incorporated by reference in this application.

I. Field of the Invention

The present invention relates generally to the field of external counterpulsation

10   therapy (ECP), and more specifically, to a method for optimizing the patient outcome from such therapy. The disclosed method enables physicians to improve the setting of the cuff inflation pressure and the timing parameters of the inflation pulse. In addition, the present invention provides feedback during long-term follow-up in patients with heart disease who are being treated with ECP.

15   ### II. Related Art

External counterpulsation (ECP) has been recently FDA approved as a new indication of therapy for the treatment of patients with heart failure (HF) and angina. Although ECP has been shown to improve patient morbidity or their quality of life (QOL), there has been limited success in demonstrating its effect on patient mortality.

20   The ECP technician is required to manually adjust the timing delays between the R-wave and the start of pressurization of the cuffs located on the patient by observing blood pressure and/or oxygen saturation. The main disadvantage of this technique is that the blood pressure signal is too distal, somewhat distorted, and does not reflect upon kinetic changes in heart and lung function. Cuff pressure is currently fixed –

25   from 220 mmHg to 385 mmHG. The physiologic consequences, in terms of circulation and gas exchange, of using either pressure is poorly understood at present. Additionally, there is no technique for assessing chronic adaptation of patient physiology to ECP therapy.

Definition of Terms

30   The following contains definitions and explanations of certain terms as used in the present context.

End-Tidal Partial Pressure of CO_2 (PetCO$_2$, ETCO$_2$) – The partial pressure of carbon dioxide at the end of expiration, or the highest value of PCO_2 during a single expiration.

Forward Pump Function - Refers to the ability of the heart to contract and eject blood which has returned to the heart during its relaxation, or filling, cycle via the aorta against a given amount of resistance, or afterload.

Outcome Measurement: With the individualized set of parameters optimally selected as described, the next step is to make an overall assessment of the patient's risk factors over time. In order to appropriately assess the patient's risk factors that are, in turn, related closely to adverse patient outcomes, the patient must be stressed (normally by mild to moderate exercise) in order to evaluate changes in the sympathetic and parasympathetic components of autonomic balance during dynamic, isotonic exercise and recovery. In other words, a volume load must be placed on the heart in order to assess the cardiopulmonary system's true response to patient activity. It is the same with the assessment of cardiac ischemia using the classical ECG stress test. Some type of exercise modality must be used in order to stress the heart and create an imbalance in myocardial oxygen supply and demand. Unlike the classical ECG stress test, maximal exercise intensity is unnecessary to obtain the measured data. Instead, exercise intensities that reflect those normally experienced by the patient's activities of daily living are used to provide the volume load. Several known predictors of mortality in HF patients are measured during application of the volume load, including ventilatory efficiency slope, oxygen efficiency slope, aerobic power, and the chronotropic response index. Individual and cumulative mortality prediction indices, Kaplan-Meier Plots, and trend graphs are provided to document outcomes status due to supportive therapy with external counterpulsation.

Oxygen Pulse (O_2 Pulse) – O_2 Pulse is an indirect index of combined cardiopulmonary oxygen transport. It is calculated by dividing oxygen uptake (ml/min) by heart rate. In effect, O_2 Pulse is equal to the product of stroke volume and arteriovenous O_2 difference. Thus circulatory adjustments that occur during exercise, that is, widening arteriovenous O_2 difference, increased cardiac output, and redistribution of blood flow to the working muscle, will increase O_2 Pulse. Maximal O_2 pulse is higher in fitter subjects, lower in the presence of heart disease, and, more

importantly, higher at any given workload in the fitter or healthier individual. On the other hand, O_2 Pulse will be reduced in any condition that reduces stroke volume....."
V. Froelicher, J. Myers, et al., Exercise and the Heart. Mosby-Year Book, Inc. 1993, p.38

5   **Retrograde Pump Function** - Refers to the filling of the heart during the relaxation part of the cardiac cycle. Filling pressure and the volume of blood that returns to the heart during diastole are termed preload. Any forward pump failure of the heart can increase the preload on the heart to undesirable levels which, in turn, has an adverse retrograde effect on gas exchange in the lung.

10   **Ventilation-Perfusion Coupling** – "For gas exchange to be most efficient, there must be a precise match, or coupling, between ventilation (the amount of gas reaching the alveoli) and perfusion (the blood flow in pulmonary capillaries). Changes in the PCO_2 within the alveoli cause changes in the diameters of the bronchioles. Passageways servicing areas where alveolar carbon dioxide levels are high dilate, allowing carbon

15   dioxide to be eliminated from the body more rapidly; those servicing areas where the PCO_2 is low constrict. As a result of the modifications these two systems (also for PO_2), alveolar ventilation and pulmonary perfusion are always synchronized. Poor alveolar ventilation results in low oxygen and high carbon dioxide levels in the alveoli; consequently, the pulmonary capillaries constrict and the airways dilate,

20   bringing airflow and blood flow into closer physiological match. High oxygen and low carbon dioxide alveolar partial pressures cause constriction of the respiratory passageways and a flushing of blood into the pulmonary capillaries. At all times, these homeostatic mechanisms provide the most appropriate conditions for efficient gas exchange." E. Marieb, Human Anatomy and Physiology. Benjamin/Cummings

25   Publishing Company, 1992, p.749

      Ventilatory Efficiency Slope (of Ventilation vs. VCO_2) - The recorded test data contain the channels minute ventilation VE and carbon dioxide output VCO_2 as time series with sample points (moments of time) t_i, so there are two sets of data points VE_i and VCO_{2i} with i-1,..., N. To find the best straight line fit $VE=a\ VCO_2 + b$ to the

30   ensemble of point pairs (VE_i, VCO_{2i}) one can use the linear regression analysis minimizing the sum of squares of distances of these points to a straight line, see for instance PRESS, W.H., B.P. FLANNERY, S.A. TEUKOLSKY, W.T.

VETTERLING:; Numerical Recipes, The Art of Scientific Computing. Cambridge University Press, Cambridge etc., 1986, Chapter 14.2. The main results of such an analysis are the constants a and b describing the regression line and the regression coefficient r as a measure for the regularity of data lying along and around this line.

5 The constant a is the VE to VCO_2 slope, or ventilatory efficiency slope, of the above mentioned data ensemble.

Ventilatory Equivalent for carbon dioxide (VE/VCO$_2$, EQCO$_2$) – The $EQCO_2$ is calculated by dividing ventilation (L/min) by VCO_2 (L/min). "VE/VCO_2 represents the ventilatory requirement to eliminate a given amount of CO_2 produced by the

10 metabolizing tissues. Since metabolic CO_2 is a strong stimulus for ventilation during exercise, VE and VCO_2 closely mirror one another, and after a drop in early exercise, VE/VCO_2 normally does not increase significantly throughout sub-maximal exercise. However, in the presence of chronic heart failure, VE/VCO_2 is shifted upward compared to normals, and high VE/VCO_2 values are one of the characteristics of the

15 abnormal ventilatory response to exercise in this condition." Ibid Froehlicher.

SUMMARY OF THE INVENTION

The present invention, to a large extent, obviates the problems discussed in the foregoing for each of the phases described above. The physiology supportive of the present invention involves the relationship of the pulmonary circulation and gas

20 exchange in the lungs that will readily reflect upon ventricular filling pressures, pulmonary venous flow, and ventilation to perfusion matching in the lungs (see also Definitions). A sound physiologic basis exists to support the theory that the oxygen pulse (O_2 Pulse), end-expired, partial pressure of CO_2 ($ETCO_2$), and ventilatory equivalents of CO_2 ($EQCO_2$) are key parameters to assess pump function of the heart

25 and the efficiency of gas exchange in the lungs. Any therapy, which reduces stroke output of the heart, may cause a volume load on the heart, thus affecting the pulmonary venous blood flow gradient and ventilation to perfusion matching in the lungs. When ventilation to perfusion is mismatched, the $ETCO_2$ and O_2 Pulse will be reduced and $EQCO_2$ will be increased. Because gas exchange measurements are made

30 on a "breath-by-breath" basis, physiologic changes resulting from altering timing delay and cuff pressure setting are observable more or less instantaneously, thus they can be used to guide the decision making process in either case.

The individualized programmed set of parameters will differ for each patient, reflecting the fact that each patient has unique cardiac and pulmonary function.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Figure 1 is a schematic drawing that illustrates the functional components of a CPX testing system usable with the present invention;

Figure 2 is a schematic drawing that illustrates the functional components of an external counterpulsation system;

Figure 3 illustrates the data display viewed by the physician while acquiring data using the present invention;

Figure 4 illustrates a Boundary Conditions Table for a particular ECP system;

Figure 5 illustrates a CID/CIP Optimization Protocol showing when particular tasks occur;

Figure 6 illustrates the organization of the measured data once it is acquired during the Optimization Protocol;

Figure 7 illustrates the organization of Intermediate Data after each 1.5 minute segment of the Optimization Protocol;

Figure 8 illustrates the organization of the Decision Matrix and sample values for the calculated results;

Figure 9 illustrates a Report Summary in a histogram format for the data used in Figure 8.

DETAILED DESCRIPTION

The following detailed description with respect to patient data is intended to be exemplary of a preferred method of utilizing the concepts of the present invention and is not intended to be exhaustive or limiting in any manner with respect to similar methods and additional or other steps which might occur to those skilled in the art. The following description further utilizes illustrative examples, which are believed sufficient to convey an adequate understanding of the broader concepts to those skilled in the art, and exhaustive examples are believed unnecessary.

General Considerations - The present invention is not intended to make decisions, but rather to provide information to guide the decision making process by the physician. In doing so, decisions regarding cuff inflation pressure and timing

delays can be made. In some cases, the answer to these questions may be no – there is no clear reason to use one choice over another. Even in this case, the decision making process described in the present invention is an improvement over a process devoid of specific, sensitive data. In the present invention, specificity is provided by a quantitative analysis of response variables that are based upon well known, proven measurements of human physiology. Sensitivity is supported by qualitative assessments of the measurements themselves.

The present invention also provides information that can be used to make decisions acutely (is the new cuff inflation pressure better than the last pressure?) and chronically (has patient mortality been improved as a result of the therapy?). In the latter case, factors such as chronic adaptation to exercise and therapies other than ECP may influence changes in the patient's condition. Since the general objective of all patient therapy is to improve patient outcome, characterized by the individual patient's mortality risk profile, the decision-making tools described in the present invention increase the likelihood that ECP will contribute to improved patient outcome.

The general class of data utilized in the present invention, dynamic-cardiopulmonary (DCP), is obtained at rest during the ECP session. Such data can be viewed as an "acute" evaluation of the primary "endpoint" to gauge the effect of ECP on hemodynamic and pulmonary performance and on left ventricular stroke volume. A chronic assessment of ECP is then preformed using the optimal cuff inflation pressures and timing delay settings determined during the acute phase to observe patient status in terms of risk of death. When performed sequentially over time, changes in risk factors can be measured to help determine whether patient outcome is improving (reduction in mortality factors) or deteriorating. In the latter case, additional ECP therapy is an option that can be considered by the physician.

The physiologic changes are measured using a cardiopulmonary exercise testing system (CPX) to measure selected variables associated with expired oxygen, carbon dioxide, ventilation, and heart rate. In theory, certain benefits derived from the present invention could be implemented using only a carbon dioxide analyzer equipped with a means for displaying the expired CO_2 waveform. However, because of the requirement for measuring "forward" pump function, both heart rate and

oxygen consumption, per breath, are needed to measure O_2 Pulse. Consequently, a carbon dioxide analyzer alone is insufficient.

During the acute phase of evaluation, the dependent variables, $ETCO_2$, $EQCO_2$, O_2 Pulse, and the ventilatory efficiency slope, are measured during steady-
state conditions at rest. In the present invention, the independent variables are 1) cuff inflation pressure (CIP), and 2) the cuff inflation delay (CID) values. Thus, changes made by the physician to an independent variable have the effect of changing the ventricular filling and stroke output of the heart that, in turn, alters the ventilation-perfusion coupling. As the local autoregulatory mechanisms seek to restore the synchronization of alveolar and pulmonary perfusion, the dependent variables rapidly change, are measured, and the measured values are automatically scaled and displayed to provide visual feedback to the physician during cuff inflation pressure and delay selection. In doing so, a physician is provided with a true, physiologic assessment of the patient's condition resulting from changes made to an independent variable at any point in time during the procedure.

By also providing a chronic assessment of mortality data over time, the physician can better understand the consequence of any given therapeutic action whether from ECP alone or in combination with other medical therapy. By providing a closed-loop system of action (therapy) and physiologic response (to therapy), the quality of providing ECP will be increased and the cost reduced.

The data gathering aspect of the invention involves known techniques and analyses and it is the aspects of processing, combining, and presenting the data in which the invention enables an observer to gain new and valuable insight into the present condition and condition trends in patents. Thus, in accordance with the preferred method, a dynamic cardiopulmonary analysis is displayed for each data set. The performance of such a test is well understood by individuals skilled in the art, and no further explanation of this, except for the cuff inflation pressure/delay optimization protocol, is believed necessary.

Equipment - With this in mind typical hardware is shown in Figure 1, which illustrates typical equipment whereby a cardiopulmonary exercise test (CPX) may be conducted and the results displayed in accordance with the method of the present invention. The system is seen to include a data processing device, here shown as a

personal computer of PC 12, which comprises a video display terminal 14 with associated mouse 16, report printer 17 and a keyboard 18. The system further has a floppy disc handler 20 with associated floppy disc 22. As is well known in the art, the floppy-disc handler 20 input/output interfaces comprise read/write devices for reading prerecorded information stored, deleting, adding or changing recorded information, on a machine-readable medium, i.e., a floppy disc, and for providing signals which can be considered as data or operands to be manipulated in accordance with a software program loaded into the RAM or ROM memory (not shown) included in the computing module 12.

The equipment used in the exercise protocol for the chronic assessment includes either a bicycle ergometer or treadmill designed for use in a cardiopulmonary stress testing system (CPX) as is represented at 28 together with a subject 30 operating a pedal crank input device 32 of the ergometer. A graphic display device 34 interfaces with the subject during operation of the CPX device The physiological variables may be selected from heart rate (HR), ventilation (VE), rate of oxygen uptake or consumption (VO_2) and carbon dioxide production (VCO_2) or other variables derived from these basic measurements. Physiological data collected is fed into the computing module 12 via a conductor 31, or other communication device.

The equipment used in providing ECP therapy is schematically illustrated in Figure 2. The equipment includes **(can't read the material contained on Figure 2).** The equipment includes a compressor system including parallel units 40, 42, 44 and 46, which supply an air tank 48 which, in turn, supplies air to a valve assembly 50. The valve assembly 50 supplies air to hoses which are used to inflate the cuffs in accordance with the testing procedure of the invention at 52. Pressure relief is provided for the air tank by a relief valve 54 and to the valve assembly via pressure relief valve 56. The cuffs are exhausted to the room when deflated by an exhaust valve depicted by the box 58. An electronic control system as shown including connected software monitoring and alarm system 57 and electronic valve control 59.

It should be noted that either a PC (12) or the ECP microcontroller (50) could be used to acquire the measurements and process those measurements to implement the present invention. Therefore, the further detailed description of the present

invention will be made independent of the type and characteristics of the data processing means.

Acute Assessment – Optimal Cuff Inflation Pressure and Delay During ECP Therapy

5   The present invention provides a feedback mechanism to gauge the effectiveness of the choices for cuff inflation pressure and delay settings. Since the main objective of ECP therapy itself is improved hemodynamic and pulmonary performance, the present invention provides a direct measurement of hemodynamic and pulmonary performance that can be used in real-time to evaluate if the choices are

10   optimally reached. This can be determined on a relative basis for different inflation pressures and delay factors using a display of these variables as shown in Figure 3 Variable Display.

The present invention further provides a computer assisted optimizing process for optimizing cuff inflation pressures and timing delays between the R-wave and the

15   start of pressurization of the cuffs located on the patient. An "acute assessment" of any combination of cuff inflation pressure and timing delay that can be programmed is obtained by monitoring of parameters indicative of the patient's forward pump function or stroke volume output, as well as retrograde effects on filling pressures, pulmonary venous flow, and gas exchange at the alveolar/capillary membrane

20   interface. The best choices are O_2 Pulse for "forward" pump function and $EQCO_2$ for "retrograde" effects. However, in order to further refine the selection process, additional measurements such as the linear ventilatory efficiency slope [Minute Ventilation (VE) to expired Carbon Dioxide (VCO_2) slope] and $ETCO_2$ can be included. The most optimally programmed cuff inflation pressure and timing delays

25   will result in the highest expired $ETCO_2$ and O_2 Pulse values and the best ventilation efficiency (lowest linear slope) and lowest $EQCO_2$ during ECP therapy.

These parameters are measured at pre-determined values for cuff inflation pressure and timing delay, as defined in the table identified in Figure 4 as Boundary Conditions. A unique table of Boundary Conditions is established for each

30   manufacturer of ECP systems, and the size of the table, in terms of number of rows and number of columns, can be adjusted to accommodate many different such devices. In the example provided in Figure 4, three values of cuff inflation pressure

(CIP) are stored that correspond to minimum (60), average (62), and maximum (64) pressure values allowable by the ECP system. Similarly, three values of cuff inflation delay (CID) are stored that correspond to the minimum (66), average (68), and maximum (70) delay values allowable by the ECP system. To expedite the procedure, the data collection phase is divided into two, 4.5-minute sessions while the patient is undergoing ECP therapy (Figure 5 – Optimization Protocol). During the first 4.5 minutes, the three values of cuff inflation delay are sequentially programmed into the ECP controller every 1.5 minutes. This programming can be accomplished manually or automatically. After zeroing all entries, all measured data for each breath during the 1.5-minute collection period associated with each of the three cuff inflation delay values is stored into the tables at 82 in Figure 6.

Upon completion of each of the 1.5-minute data collection periods, the central tendency and deviation percentage of each measured variable is computed and, after zeroing all entries, stored in an Intermediate Table as described in Figure 7. Only data for breaths recorded during the last one minute of each collection period is used in the calculations. Such computations of central tendency can include, but is not limited to, the simple arithmetic average, as at 102 in Figure 7 for example. The Deviation % as in 104 is first calculated by summing, for each breath in the one-minute calculation period, the absolute value of the difference between the average value 102 and the recorded value. This total is then divided by the product of the number of breaths in the calculation period times the average value 102. Multiplying this calculation by 100 yields the Deviation % 104. The Deviation % is intended to provide a qualitative assessment of the "tightness" of the data sets. In other words, a small Deviation % is indicative of low variability of the data in each set, hence a high quality test. A large value of Deviation % would indicate unwanted patient events (coughing, for example) or unwanted physiologic consequences (Cheyne-Stoke breathing patterns, for example).

Upon completion of the first 4.5 minutes of data collection, further processing of the data stored in the Intermediate Table is performed. The Decision Matrix as in the example shown in Figure 8 is first zeroed, and the following steps are taken to calculate the values for each row and column.

Step 1 – Assign Rank - The Rank value is intended to provide a qualitative assessment of the optimal choice for either cuff inflation pressure or cuff inflation delay. First, the highest average value for O_2 Pulse and $ETCO_2$ and the lowest average value for $EQCO_2$ and V.E. slope are identified. A Rank value of 100 is assigned to the

5   corresponding position in the Decision Matrix for each such determination. For example, if the highest value found in column 2, rows 3-5, in Figure 7 was at row 4, or CID ave, then 100 is assigned in Figure 8 to column 2 in the row defined as CID ave. The associated value for Deviation % found in Figure 7 is also stored in the next column in the same row of Figure 8. Next, the lowest average value for O_2 Pulse and

10      $ETCO_2$ and the highest average value for $EQCO_2$ and V.E. slope are identified. A Rank value of 50 is assigned to the corresponding position in the Decision Matrix for each such determination. For example, if the lowest value found in column 2, rows 3-5, in Figure 7 was at row 5, or CID max, then 50 is assigned in Figure 8 to column 2 in the row defined as CID max. The associated value for Deviation % found in Figure

15   7 is also stored in the next column in the same row of Figure 8. A Rank value of 75 is then assigned to the Rank column in the row for which no entry has been previously made, and the associated value for Deviation % found in Figure 7 is also stored in the next column is the same row of Figure 8. In this manner entries will have been made in all columns for the rows identified as CID min, CID ave, and CID max except the S

20   % column and the Average of the Totals.

The next step is to compute, for each row in Figure 8 identified as CID min, CID ave, and CID max, the Average Total Rank. This is done by summing the individually assigned Rank values for each of the variables in the same row and dividing by 4. The "perfect" Average Rank, then, is 100, which indicates that each

25   variable for that particular setting is in theoretical conformance – the two that should be the highest are the highest and the two that should be the lowest are the lowest.

Step 2 Define Deviation - Similarly, the Average Deviation Percentage is calculated for each such row and stored in the column of that row identified in Figure 8 as D%.

30   **Step 3 – Define Separation** - The next step is to compute the values for Separation % for each of the rows in Figure 8 identified as CID min, CID ave, and CID max. The Separation % value provides a qualitative assessment of the difference,

or separation, between the components of Rank (in this example, average value of the variable data set at each CID setting). A small value of S% indicates that there is little measured difference between the average values of data sets at each delay setting; hence the test may prove inconclusive. The higher the value of S%, the more

5   conclusive the test results. For each of the columns for each of the variables, a value of 0 is assigned to the S% column in the row having the maximum average Rank. For example, in Figure 8, the row with the highest average Rank, 93.75, is the row CID ave, consequently, each column identified as S% is set to 0. The values for S % for each column of the remaining, unassigned rows is first computed by subtracting the

10   average value from Figure 7 for the associated row from the average value from Figure 7 for the row that has been assigned a value of 0 for S%. The absolute value of this operation is then divided by the average value from Figure 7 for the row that has been assigned a value of 0 for S%. Multiplying this operation by 100 yields S% for each of the remaining 2 rows, in this example, for each variable. In a similar fashion

15   described to compute average Rank and D %, average S% is computed for each row and stored in the S% column under Average of Totals.

The physician then prints the final report for review at 90 in Figure 5. The final report consists of a printed version of the Decision Matrix Figure 8 and a Report Summary, Figure 9, summarizing the calculations stored in the Decision Matrix in the

20   form of a histogram in this case (any other choice for graphical display is suitable). The Rank bar for each CID setting is placed on a scale with a maximum value of 100. The height of the bar for each setting is then the value of Average Rank from the Decision Matrix for that setting. To match the "bigger is better" assumption for Rank value, the height of the D % bar in Figure 9 is scaled to a value equal to 100 minus the

25   average D% for each setting. The average S% for the settings with lower average Rank values is printed below their associated setting columns. Thus, the optimal setting is quantified as the setting with the highest average Rank, and this, in turn, can be assessed qualitatively by the relative heights of the Rank columns (equal heights indicate poor quality), average Deviation % (large values indicates poor quality), and

30   Separation % (low value indicates poor quality). During a one-minute (or optionally, longer) period, the physician selects and programs the CID value at 92 in Figure 5 after first inspecting the Decision Matrix Figure 8 and the Report Summary Figure 9.

The second 6-minute data collection phase is started. Similarly, each of the CIP values defined in the Boundary Conditions Table Figure 4 are programmed every 1.5 minutes and each of the measured values for each breath is stored into the Stored Data Sets (84) identified in Figure 6. The entire process described above for selecting 5 CID is repeated in detail for selecting CIP, using instead those rows identified in Figures 6, 7, and 8 for CIP data storage. After inspecting the Decision Matrix Figure 8 and the Report Summary Figure 9 (in this case, showing CIP min, CIP ave, and CIP max), the physician then selects and programs the CIP value at 96 in Figure 5.

Upon completion of the acute phase of evaluation, the patient is ready for the 10 chronic assessment phase, which may be performed immediately after the acute assessment or at a later time.

Chronic Assessment – Assessment of Patient Risk of Death

Anderson and MacCarter have previously disclosed (U.S. Application serial number 10/138,442) a METHOD OF CARDIAC RISK ASSESSMENT, which is 15 hereby incorporated by reference in its entirety herein for any purpose. This describes a method of data management for assessing a patient's autonomic balance, risk of death, and the patient's response to therapy in terms of these assessments. This method describes a process by which a set of "raw variables" (RV) measured using the same equipment described in Figure 1 are translated into one or more of a new 20 variable, defined as an Mortality Prediction Index that quantifies the patient's cardiovascular reflex control. The translated variables are representative of both central and peripheral chemo receptivity, baroreflexes, and peripheral ergo receptors, which, in turn, provide the measurement of sympathovagal, or autonomic, balance. The process of selection and measurement of the MPI, and thus the sympathetic and 25 parasympathetic components of autonomic balance during dynamic, isotonic exercise and recovery is described.

The invention further defines risk of death using a Kaplan-Meier Plot for certain translated variables. The addition of this method to the present inventions will enable physicians to collect, view, track and manage hemodynamic and pulmonary 30 data to better understand the consequences of decisions made in the acute phase of the present invention and of the adaptation by the patient over time to ECP therapy.

The invention has been described in considerable detail in order to comply with the Patent Statutes and to provide those skilled in the art with the information needed to apply the novel principles and to construct and use such specialized components as are required. However, it is to be understood that the invention can be carried out by specifically different equipment and devices, and that various modifications, both as the equipment details and operating procedures can be accomplished without departing from the scope of the invention itself.